the application of a suitable voltage to the modulator crystal, each set of longitudinal modes can be phase locked as an FM signal by itself. However, in order to assure FM where the instantaneous frequency excursion is equal and opposite for both sets of modes, one needs a modulator crystal, where an increase in the dielectric constant in x direction is accompanied by a decrease of dielectric constant of the same magnitude in y direction, for example. This is indeed the case for KDP if the modulating voltage is applied in z direction, which is also the direction of light propagation in the laser cavity, and if the crystallographic a and b axes have an angle of 45° with respect to x or y.

In practice, it will be necessary to have all elements in the laser cavity carefully antireflex coated in order to suppress incidental mode selection.

It would be interesting to realize this type of operation for the argon ion laser that offers a high fundamental intensity. It would be particularly intriguing to obtain high intensity UV coherent light in this fashion. Unfortunately, no nonlinear crystal, which would satisfy the phase matching condition in the described fashion, is known to us.

On the other hand, a practical although perhaps not high efficiency realization of this proposal is possible, with the 1.15 μm line of He–Ne as fundamental and a KDP crystal for nonlinear interaction. Phase matching then occurs at $\vartheta_0 = 59° 58'$ and the azimuthal angle should be $\varphi = 0°$ or $\varphi = 90°$, for maximum efficiency.

As shown by Smith's argument,[6] the scheme described should offer harmonic output with near unity efficiency, if the nonlinearity of the crystal is high, if the electric field of the fundamental frequency modes is high, and if incidental losses in the cavity can be kept small.

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References

[1] S. E. Harris and B. J. McMurtry, "Frequency selective coupling to the FM laser," *Appl. Phys. Lett.*, vol. 7, pp. 265–267, November 1965.
[2] G. A. Massey, M. K. Oshman, and R. Targ, "Generation of single frequency light using the FM laser," *Appl. Phys. Lett.*, vol. 6, pp. 10–11, January 1965.
[3] H. P. Weber, E. Mathieu, and K. P. Meyer, "Optical mixing with different relative polarizations of the beams," *J. Appl. Phys.*, vol. 37, pp. 3584–3586, August 1966.
[4] H. P. Weber and E. Mathieu, "Ueber die Erzeugung der 2. harmonischen Frequenz der Strahlung eines Nd-Lasers in KDP," *ZAMP*, vol. 17, pp. 477–478, June 1966.
[5] S. E. Harris and R. Targ, "FM oscillation of the He-Ne laser," *Appl. Phys. Lett.*, vol. 5, pp. 202–204, November 1964.
[6] R. G. Smith, "Efficient continuous optical second harmonic generation," *IEEE J. Quantum Electronics (Abstract)*, QE-2, p. xli, April 1966.
[7] A. Ashkin, G. D. Boyd and J. M. Dziedzic, "Resonant optical second harmonic generation and mixing," *IEEE J. Quantum Electronics*, vol. QE-2, pp. 109–124, June 1966.

Correction

E. Garmire and A. Yariv, authors of "Laser Mode-Locking with Saturable Absorbers," which appeared on pp. 222–226 of the June, 1967, issue of this JOURNAL, have called the following to the attention of the Editor.

Equation (11) and following should read:

$$\frac{ST}{3} = 1 - \frac{L_a N_a \sigma_a + \beta - L_r N_r \sigma_r}{\sigma_a E N_a L_a \sigma_a}.$$

The energy-dependent term has the form of

$$\frac{\text{percent absorber nonlinearity}}{\text{degree of dye saturation}}.$$

Percent absorber nonlinearity is the nonlinear term in the loss (equals linear loss − linear gain) divided by the absorber loss. The degree of dye saturation $\sigma_a E$ is roughly the number of photons absorbed by the dye per pass divided by the number of dye molecules or $E_{a1}/2N_a L_a$ [See eq. (8)]. In typical cases, this is about 0.3. For 10 percent absorber nonlinearity, $ST \sim 2$.

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